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(54) A PLASMA ARC GENERATOR

(71) I, The Manager of the Academia Republicii Socialiste Romania, of cal. Victoriei, 133, Bucharest, Romania, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a plasma arc generator, operating with a d.c. or a.c. supply and having improved characteristics by virtue of arrangements for rotating the arc and the injected gas, which may be air or nitrogen for example. The plasma arc generator, is suitable for cutting, welding, build-up welding, (i.e. welding in which a deposit of metal is built-up), metallizing and promoting chemical reactions.

Numerous types of plasma arc generators are known and utilized for cutting, build-up welding or metallizing, with or without a transferred arc. These generators, if utilized in systems with a transferred arc, present the disadvantage that they require the use of gas mixtures without oxygen or, in order to protect the cathode, the simultaneous utilization of an inert shielding gas too, e.g. argon. For this reason the known methods for cutting or build-up welding or metallization have a reduced economical efficiency and due to the reduced concentration of the plasma arc, especially if utilized for the cutting of metals, they need a high consumption of electrical energy, and their efficiency and productivity is low.

There are also known plasma arc generators with magnetic focusing, the magnetic field being generated by coils placed on the body of the generator over the combustion chamber or at the output end of the nozzle. These types of plasma generators present the disadvantage that, because of the high dispersion of the magnetic flux and of the lack of field concentrators, their focusing efficiency is low, or the disadvantage that due to the position of the coil at the output end of the nozzle, protection of the electrode is not realized.

There are further known plasma generators fed with single phase alternating current, these generators presenting the disadvantage of the instability of the arc, which needs the permanent utilization in the arc circuit of a high frequency oscillator with high voltage pulses. These generators load the distribution net work asymmetrically and cannot be utilized in systems with a transferred arc.

Known three-phase plasma arc generators need two or three electrodes, and for this reason the gas utilized must not contain oxygen and the thermal plasma obtained has a low degree of ionization. It must also be mentioned that the efficiency of such an installation, as used especially for promoting chemical reactions, is relatively low. As the electrodes are placed on different axes, which cannot coincide with the axis of the nozzle, this nozzle can have only a limited contraction; thus the degree of concentration of the thermal plasma produced in this way is also reduced.

Such generators cannot be utilized for welding, build-up welding or metallization, being suited only for special chemical reactions and they are characterized by a low efficiency and a rapid consumption of the electrodes.

The present invention enables all these disadvantages to be avoided or reduced.

According to the present invention there is provided a plasma arc generator comprising a nozzle, means for feeding gas through the nozzle and also through a peripheral passage around the nozzle, current supply means for establishing an arc between the nozzle and an electrode within the nozzle, the current supply means including a first coil which carries the whole of the nozzle current and embraces a ferromagnetic core surrounding the nozzle, and the generator also including a second coil embracing a

second ferromagnetic core disposed coaxially around the electrode behind the first said core for creating a low pressure zone at the said electrode to protect the same.

The two coils cause simultaneous rotation of the plasma arc inside as well as outside the nozzle and the introduction of air and other gases through the nozzle as well as outside the nozzle can be effected as to impart rotary motion to the gases. The relative senses of rotation can be so chosen as to increase the enthalpy and increase or reduce the consumption of energy, as appropriate for each application. Since air, instead of other gases, can be used in the case of cutting the economic efficiency is increased also.

The generator can readily be modified for a.c. use with a single electrode by using two mutually insulated nozzles, both coaxial with the jet axis. The phases of a three phase supply arc connected to the electrode and two nozzles respectively. This permits gas mixture containing oxygen to be used without causing consumption of the electrode. Due to the rotation of the arc and to the direct injection of additional turbulent gas in the arc zone after the first nozzle, the efficiency of the generator is very high.

The invention will be described in more detail, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a sectional view of a plasma arc generator embodying the invention, for direct current operation.

Fig. 2 is a fragmentary lateral view taken in the direction of an arrow C in Fig. 1,

Figs. 3 to 5 are sections taken on lines A—A, B—B and D—D respectively in Fig. 1, and

Fig. 6 illustrates the principle of design for three-phase a.c. operation, of the generator shown in Fig. 1.

In the following will be described the functioning of the generator embodying the invention, in the case of cutting.

The generator of Fig. 1 generates an electric arc between a tungsten electrode 1 and a nozzle 2, electrically isolated by a ceramic insulator 3 and a textolite insulator 4. The air Qp (or other gaseous mixture) is introduced through a pipe connector 5 into an equalization chamber 6. Helical channels *6a* provided around an outwardly flared part of the outer portion *7a* of an electrode holder cause the gas to execute a turbulent motion, with a speed increasing as the front part of the inner portion *7b* of the electrode holder tapers back downwardly within a correspondingly inwardly tapered passage through the insulator 4. The maximum speed is reached at the lower end, in the zone between the ceramic insulator 3 and the cone of the inner portion of the electrode holder. An adiabatic expansion then takes place in the zone of the nozzle 2. Due to the rotation of the air Qp caused by the helical channels and especially to that of the electric arc, caused by a magnetic field generated by a coil 8 and concentrated by a core 9, upon which is superposed a second field generated by a coil 10 and a core 11, a low pressure zone is produced around the electrode, which protects the electrode from oxidation. The core 9 is behind the core 11, coaxially surrounding the electrode 1.

In the case of cutting of metals, the sense of rotation of the arc created electromagnetically by the two coils 8 and 10 is the same as the sense of rotation of the gas Qp caused by the helical channels *6a*.

The rotation of the plasma jet caused by the intense magnetic field generated in the outside zone of the nozzle 2 by the coil 10, through which passes the entire current of the nozzle 2, creates a depression outside the nozzle 2, too.

In this depression zone, a jet of air Qs or of other gaseous mixture (methane gas, hydrogen etc.) is injected through a pipe connection 12, this jet also having a turbulent character, due to the action of helical channels *a*, provided round the nozzle 2, in the zone between the nozzle and a copper ring 13 shrouding the end of the nozzle. The superposition of the effects due to the intense magnetic field in the arc zone, generated by the coil 10 and concentrated by the core 11 and also due to the turbulent jet of air (or gas) Qs, causes a pronounced concentration of the electric arc between the electrode 1 and a metal work piece P. In the case of welding the rotation of the plasma jet caused by the coil 10 is in the opposite sense to the rotation of the gas Qs imparted by the channels *a*.

The high rotation speed of the electric arc and of the plasma jet outside the nozzle 2 which displaces centrifugally also the unionized particles of gas, in the entire zone of the electrical discharge, increases the vacuum surrounding the electrode 1, which prevents the consumption in the presence of oxygen, contained by the gas Qp.

Due to the electromagnetic forces generated by the coil 10 at the lower part of the generator and to the mechanical forces generated by the turbulent motion of the jet of air Qs issuing through the passages *a*, the plasma jet rotates outside the nozzle too (the direction of the arc rotation being the same as that of the gas Qs in the case of the cutting of metals) maintaining its position on the geometrical axis of the generator.

When the generator is used for cutting, all rotations are made in the same sense both inside and outside the nozzle. Then the kinetic energy of the particles from the peripheral zone of the arc reaches a very

high value which blows the molten metal strongly away from the cut channel, without the need of guiding the gas in an axial direction, as in the usual case of classical plasma generators, which need therefore an increased gas flow Qp.

The mutual actions between the two magnetic fields (which are of the same sense in the case of cutting) and the electrical particles from the arc zone, cause, besides the concentrating effect, the maintaining of the electric arc in the position of the geometrical axis of the generator, both inside and outside the nozzle, after the plasma jet has left the nozzle, which increases considerably the effect of the penetration of the arm into the metal to be worked and avoids the need of mechanically centering the electrode or the nozzle in the direction of the generator axis.

The electrode 1 is thoroughly cooled by the turbulent gas Qp issuing from the channels 6*a* and by cooling water, introduced into the annular space between the inner and outer portions 7*b* and 7*a* of the electrode-holder by a connecting piece 14, Fig. 1, and evacuated by another connecting piece 15 (Fig. 3). The connecting piece 15 also serves for the feeding with electrical energy, from the cable 16 (Fig. 5), led in through the water duct 17, Fig. 5. Due to the conical form of the lower part of the inner electrode holder portion 7*b* (Fig. 1), the tungsten electrode is cooled up to the level of the cathodic spot, being at the same time protected against oxidation.

The effect of oxidation is thus reduced, due to the depression caused by the working gas Qp (which may be air) and due also to the intense cooling of the electrode holder 7*a*, 7*b*. To enhance these effects the generator has helical channels *b*, situated between the insulators 3 and 4 and a body 18 of the nozzle 2, through which the gas QE which is a part of the gas Qp is evacuated.

The gas QE drawn off from the discharging zone by an ejector 19, Fig. 1, which communicates with the channels *b*, is re-introduced through the connection 12, mixed with the air or other gaseous mixture Qs introduced from the outside through a pipe 19*a* (Figs. 1 and 2) feeding the ejector 19, thus participating both in the concentration of the arc in the outside zone, due to the rotation of the arc and to the increasing of the enthalpy of the plasma, after the plasma has left the nozzle 2.

The nozzle 2 is directly cooled by water passing through connections 20 and 21 (Fig. 4).

The nozzle 2 is fed with electrical energy through a resistor R1, cable 22 (Fig. 1), an intermediate connector 23*a* and the copper band turns of the non-insulated series coil 10. The turns of the coils 10 are connected by a screw 23*b* (Figs. 1 and 4) to the body 18 of the nozzle 2.

The sealing of the nozzle 2 is effected by two packings 24 and 25, clamped by the core 11, which core is screwed against the body 18. The sealing of the two electrode holder portions 7*a* and 7*b* is effected by two rubber packings 26 and 27, clamped by a nut 28.

As the electrode 1 is consumed only after a very long time, no advancing devices are needed for automatic feed of the electrode. The electrode 1 being accurately dimensioned, it is maintained in the necessary position by the tightness of the fit in the socket provided in the lower part of the inner electrode holder portion 7*b*.

If the generator is utilized for welding or for build-up welding, with an externally fed welding wire, the efficiency of utilization is increased due to the opposite sense of rotation of the arc in the zone of the cathode of the electrode 1 with respect to that of the jet outside the nozzle 2. The opposite sense of rotation of the arc inside the nozzle 2 with respect to that of the gas Qp, on one hand, and the opposite sense of rotation of the plasma jet outside the nozzle 2 with respect to that of the gas Qs+QE on the other hand, leads to a high heat exchange. Due to this fact the entire volume of the introduced gas is ionized and the effect of elimination of the molten metal is considerably reduced in the case of welding.

If the generator is utilized for metallising or for ceramic deposits, the metallic (or ceramic) powder is introduced through the pipe 19*a*, the ejector 19, the pipe connection 12, and the channels *a*. In this case, the nozzle 2, with helical channels *a*, will be replaced by another nozzle 2 having the channels *a* in the form of straight lines following the generating lines of the cone of the nozzle.

In all cases the generator may work with or without a transferred arc.

As the speed of the rotational motion of the gas is very high, and due to the local cooling of the nozzle 2, caused by the external rotation of the plasma jet and the electric arc, the generator can be utilized in alternating single phase or polyphase systems.

Figure 6 illustrates the principle of design for three-phase a.c. operation of the generator shown in Fig. 1. In this case, instead of the nozzle 2, there is utilized a nozzle which is split into two mutually insulated nozzles 30 and 31 both co-axial with the jet axis but axially spaced from each other. Three phases R, S and T of a three phase supply are connected to the electrode 29 and the nozzles 30 and 31 respectively. Three arcs are established: an arc *c* between the electrode 29 and the nozzle 30, an arc *d* between the

electrode 29 and the nozzle 31 and an arc *e* between the nozzles 30 and 31. The three arcs are struck in cyclic sequence and, due to the rotation of the arcs and to the high speed of the gas flow, the anodic spots will discontinuously change their position on the nozzles, while the cathodic spot remains fixed on the electrode 29. As long as the potential of the electrode is more negative than that of the two nozzles, there will also exist the conditions for acceleration of the electrons in the ionized space between the two arcs *c* and *d* and consequently the respective currents will flow.

The nozzles can operate successively as cathodes, without being damaged, thus realizing a permanent stable burning of the arcs.

The intense cooling of the nozzles, and also the rotation of the two arcs *c*, *d* prevents the deterioration of the nozzles. The two nozzles 30 and 31 receive current through respective coils 32 and 33, corresponding to the coils 8 and 10 respectively of Fig. 1. The changing of the sense of the current in either coil will also cause the changing of the sense of the magnetic field generated by the coil; consequently the mutual action between the magnetic field and the electric arc always leads to the same sense of rotation of the arc.

The effect of the electromagnetic rotation and the realization of the vacuum around the electrode and the nozzle 30 is as described with reference to Fig. 1.

The embodiment shown in Fig. 6 can be used to promote chemical reactions by introducing a reaction gas in the zone between the two nozzles 30, 31. Plasma arc generators according to the invention, such as the embodiments described above, have the following advantages:

(1) High efficiency and productivity of the generator when used for welding, due to the concentration of the arc and its rotation, inside and outside the nozzle, in a sense contrary to the rotation of the gas.

As a consequence of the rotation of the arc and of the gas and of the vacuum thus caused around the cathode, through the partial direct evacuation of a quantity of the gas, at the level of the electrode, without its traversing the channel of the nozzle, and as a consequence of the recuperation of this gas, by its reintroduction in the channels *a*, around the nozzle 2, the generator can work in the case of cutting, with air or with gas mixture, with a high content of oxygen, without the need of utilizing inert gases for the protection of the cathode and thus the process of cutting is economic.

(2) As the electrode is also cooled by a part of the gas Qp and by the simultaneous creation of a low pressure in the zone of the cathode and as the reutilization of the same gas in the zone outside the nozzle causes the same cooling or depression effected around the nozzle, the quantity of cooling water may be reduced or cooling water may be dispensed with.

(3) The introduction in a zone outside the nozzle of some gas mixtures, in whatever proportion, for increasing the enthalpy of the plasma arc, or for intensifying the restitution of the stored energy into the cutting zone, contributes not only to the increasing of the efficiency but it intensifies to a high degree the penetration in the metal to be worked and in the case of utilizing the plasma arc for the cutting of plates it may be utilized for plates of a higher thickness.

(4) The introduction of the gas mixture Qs+QE in a zone outside the nozzle and the electromagnetic rotation of the arc, in this zone, caused by the series-coil, determines a depression and an intense local cooling of the nozzle, thus permitting a very high concentration of the arc.

(5) In a system with a transferred arc, the utilization of a series-coil prevents entirely the possibility of the formation of a secondary arc between nozzle and workpiece.

(6) The generator can be adapted for use with alternating single, two or three phase current.

WHAT I CLAIM IS:—

1. A plasma arc generator comprising a nozzle, means for feeding gas through the nozzle and also through a peripheral passage around the nozzle, current supply means for establishing an arc between the nozzle and an electrode within the nozzle, the current supply means including a first coil which carries the whole of the nozzle current and embraces a ferromagnetic core surrounding the nozzle, and the generator also including a second coil embracing a second ferromagnetic core disposed coaxially around the electrode behind the first said core for creating a low pressure zone at the said electrode to protect the same.

2. A plasma arc generator according to claim 1, wherein the peripheral passage around the nozzle comprises helical channels.

3. A plasma arc generator according to claim 1, wherein the peripheral passage around the nozzle comprises straight channels.

4. A plasma arc generator according to claim 2, wherein the current supply means are arranged to supply current through the first coil in a sense such that the ensuing rotation of the arc is in the opposite sense

to the rotation of the gas induced by the helical channels.

5. A plasma arc generator according to claim 2 or 3, wherein the means for feeding gas through the nozzle comprise helical channels for imparting rotation to the gas in the nozzle.

6. A plasma arc generator according to any of claims 1 to 5, comprising means for evacuating part of the gas through the nozzle and for reintroducing this gas through the peripheral passage around the nozzle.

7. A plasma arc generator according to any of claims 1 to 6, comprising means for introducing a metallizing or ceramic powder with the gas which is fed through the peripheral passage.

8. A plasma arc generator according to claim 1, wherein there are two mutually insulated, axially spaced nozzles, the first coil being connected to the nozzle further from the electrode and the second coil being connected to the nozzle nearer to the electrode.

9. A plasma arc generator according to claim 8, wherein the current supply means comprise three phase lines connected to the two nozzles and the electrode respectively.

10. A plasma arc generator according to claim 8 or 9, comprising means for introducing a reaction gas in the zone between the two nozzles.

11. A plasma arc generator substantially as described with reference to and as shown in Figs. 1 to 5 of the accompanying drawings.

12. A plasma arc generator substantially as described with reference to and as shown in Figs. 1 to 5 as modified by Fig. 6 of the accompanying drawings.

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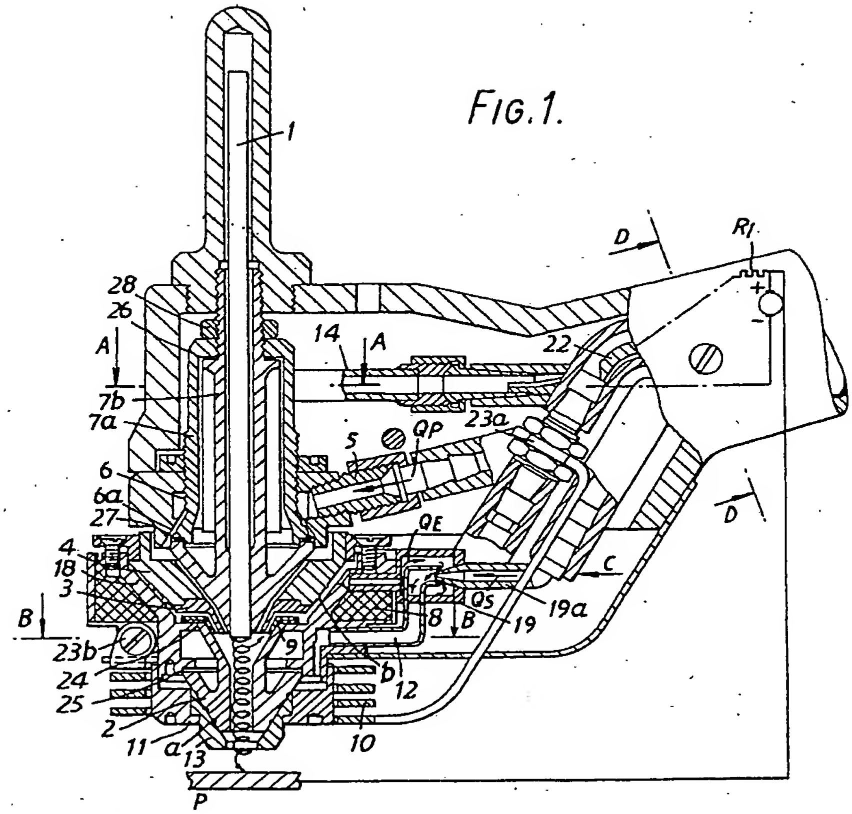
1221317 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1.



1221317 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

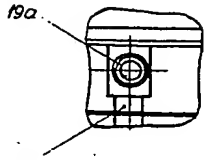


Fig. 2

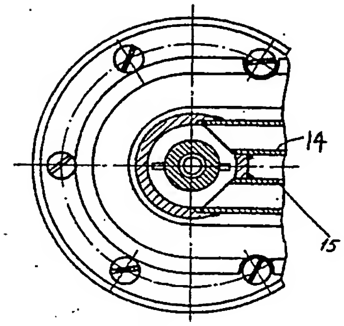


Fig. 3

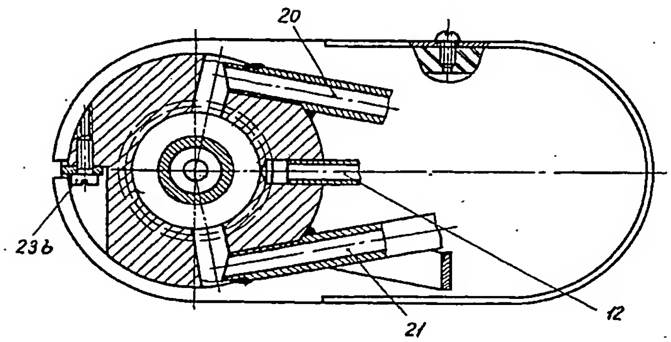


Fig. 4

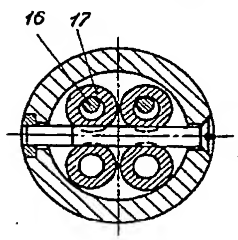


Fig. 5

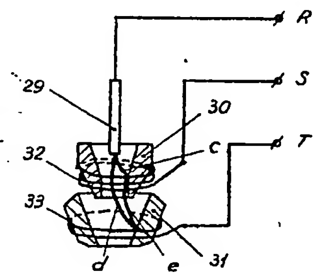


Fig. 6